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Methods for Estimating the Contribution of Unwanted Water in Sewer Networks: A Systematic Review

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Highlights:

- Challenges of Water Undue: Infiltration and inflow increases operational costs and affects effluent quality, especially in aging infrastructure.
- Data Integration: Combining methodologies improves reliability and response speed.
- Strategic Interventions: Analyzing data allows for timely maintenance and adjustments to prevent severe damage and optimize system performance..

Keywords: Sewer network management; Infiltration; Inflow.

INTRODUCTION

Wastewater in sewer systems, whether from subsurface infiltration or rainfall ingress, poses significant challenges in densely populated urban areas with aging infrastructure. This problem is exacerbated by heavy rainfall and extreme weather events, leading to leaks and environmental pollution. Research indicates that wastewater can constitute a substantial portion of the total flow in sewer pipes, contributing to network overload and increasing treatment costs (Kechavarzi et al., 2020). The extra volume not only increases operational and maintenance expenses, but also impacts effluent quality and energy consumption (Heiderscheidt et al., 2022). Effective management of wastewater requires an accurate understanding of its sources and triggers within the sewer network (Zhao et al., 2020). Estimation methods range from direct measurement techniques to sophisticated computational models, each with their own constraints and levels of accuracy. The selection of the most appropriate technique depends on several factors, such as network scale, pipe composition and resource availability, highlighting the need for careful assessment to ensure efficient management of the sewer system.

This review will present an analysis of different techniques for estimating the contribution of wastewater to the sewer network, providing an overview of the advantages and disadvantages of each. The aim is to provide researchers and practitioners with a thorough understanding of the available techniques and to help them make decisions in choosing the most appropriate contribution estimation technique for their specific needs.

METHODOLOGY

The systematic literature review used multiple sources, including scientific articles, technical manuals/reports, and other relevant resources. In the first step, specific keywords were defined based on the research question. The main terms used were combined using boolean operators such as AND and OR to refine the results. The terms used were sewer, network, infiltration and inflow. In addition, more complete searches with terms such as: infiltration, inflow, measurement, calculation, assessment, detection and investigation.The searches were conducted in databases such as Web of Science, Science Direct, and Google Scholar. This methodology ensured a comprehensive review, providing a basis for analyzing and discussing techniques for estimating the contribution of undue water in sewage systems. The figure below illustrates the review conducted.

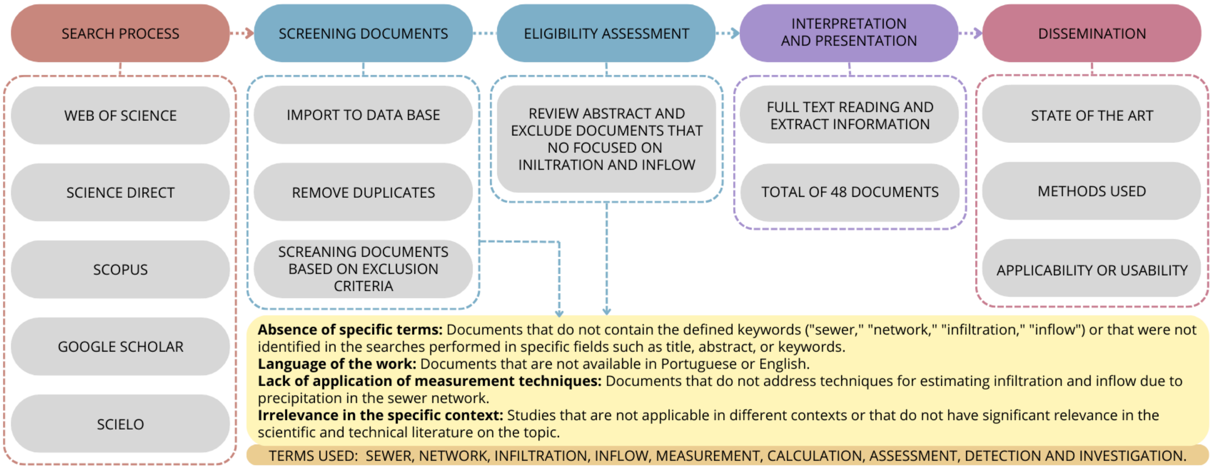

Figura 1. Systematic literature review framework.

RESULTS AND CONCLUSIONS

The review highlights the increasing concern regarding water undue in sewage networks, especially in developing countries with aging infrastructure, emphasizing the need for meticulous planning and strategic interventions. Various techniques offer different advantages and drawbacks for infiltration and inflow (I/I) assessment, making it crucial to select the most appropriate method based on system characteristics and available resources.

For temperature sensing methods, it is crucial to select sensors that are resistant to humid and corrosive environments, install the sensors in strategic locations along the network, and configure the system to collect and monitor temperature data. Analysis should identify significant variations that may indicate I/I. The temperature sensor method in sewer networks offers economical monitoring with minimal calibration and installation adjustments; however, it faces accuracy challenges due to temperature fluctuations, which can be influenced by external factors such as ambient temperature changes, flow variations, and the presence of other heat sources within the network. Schilperoort et al. (2013) introduce distributed optical sensors, effective for rainwater detection in Dutch and German sewer systems, aiding in flood prevention. Lepot et al. (2017) demonstrate infrared camera usage for identifying illicit connections in Belgium sewer system, while Cahoon and Hanke (2017) study rainfall's impact on US wastewater systems, emphasizing efficient treatment strategies. Beheshti and Sægrov (2018, 2019) propose thermal analysis and closed-circuit television inspection in Norwegian networks, aiming to reduce environmental and financial impacts. Lastly, Kechavarzi et al. (2020) suggest fiber-optic sensing for real-time monitoring, promising improved flow measurement and I/I detection.

Mathematical modeling requires choosing appropriate simulation software, configuring this software with sewer network data, collecting relevant field data, and analyzing simulations to predict system behavior and validate the model with real data. Mathematical modeling is a key approach for estimating I/I in sewer networks, enabling the creation of theoretical models representing system hydraulic behavior and environmental interactions. While offering predictive capabilities for assessing I/I control strategies, this method requires precise data for calibration and expertise in mathematics and hydraulics. Studies by Belhadj et al. (1995), Sherman et al. (1998), Wright et al. (2001), and others explore various mathematical modeling techniques for I/I estimation. These studies address factors such as rainfall-induced inflow, groundwater infiltration, and the impacts of sewer system rehabilitation. Their findings enhance our understanding of I/I sources and highlight their implications for sewer system management and environmental impact mitigation.

For sewage quality data methods, it is necessary to select and install sensors that measure parameters such as pH and turbidity, collect quality data at critical points in the network, and analyze variations to detect possible sources of I/I. Tracer methods involve selecting appropriate tracers, introducing them at strategic points in the sewer, collecting samples to monitor the presence of tracers, and analyzing the results to track the source and extent of infiltration. Methods utilizing sewer quality data and tracer methodologies provide more economical approaches for quantifying I/I in sewer networks. These methods provide insights into network hydraulic and structural conditions, aiding effective sewer system management and performance evaluation. Kracht and Gujer (2005) introduce an innovative methodology analyzing pollutant load time series to differentiate sewage and I/I loads, while Bareš et al. (2009) monitor pollutant mass flow over two years to estimate I/I contribution, offering long-term assessment without disrupting sewage flow. Tracer methodologies involve introducing tracer agents into sewage or undue water, allowing for direct and accurate assessment. These methods are adaptable to different conditions, such as varying flow rates, pipe materials, and environmental factors like temperature and chemical composition. However, they pose challenges regarding water quality impacts, costs, and data analysis time. Studies by Bertrand-Krajewski et al. (2006), Kracht et al. (2007, 2008), Prigiobbe and Giulianelli (2009), Shelton et al. (2011), De Ville et al. (2016), Zhao et al. (2020), and Heiderscheidt et al. (2022) provide insights into I/I management and seasonal patterns. These studies also demonstrate the application of tracer methodologies and sewer quality data to improve the detection and analysis of I/I sources.

Temperature sensor methods, for instance, offer simplicity but struggle with accuracy, particularly in warmer climates. Mathematical modeling provides precise estimations but depends on accurate data and requires specialized expertise. Sewer quality data methods are relatively straightforward but may lack the necessary precision, while tracer methods, though highly accurate, come with longer data analysis times. The integration of these methods, tailored to specific urban sectors (such as residential, industrial, or mixed-use areas) can enhance the reliability of I/I assessments. First, this data must be centralized and normalized to facilitate analysis. Next, exploratory analysis is performed to identify patterns and correlations, followed by modeling and simulation to predict critical areas and moments. Based on this analysis, intervention strategies are developed, including corrective and preventive maintenance actions, prioritizing critical areas and adjusting operational processes. Finally, we implement solutions, monitor the results continuously and adjust the approach as necessary, ensuring that the data is well communicated and used to inform and adjust action plans, thus preventing damage and improving system efficiency. This targeted approach allows for the combination of data sources to generate comprehensive interpretations, facilitating quick decision-making to address issues before they cause severe damage to the sewer network and compromise wastewater treatment processes.

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REFERENCES

Bareš, V., Stránský, D., Sýkora, P. (2009). Sewer infiltration/inflow: long-term monitoring based on diurnal variation of pollutant mass flux. Water Science and Technology, 60(1), 1-7.

Beheshti, M., Sægrov, S. (2018). Quantification Assessment of Extraneous Water Infiltration and Inflow by Analysis of the Thermal Behavior of the Sewer Network. Water, 10(8), 1070.

Beheshti, M., Sægrov, S. (2019). Detection of extraneous water ingress into the sewer system using tandem methods – a case study in Trondheim city. Water Science and Technology, 79(2), 231-239.

Belhadj, N., Joannis, C., Raimbault, G. (1995). Modelling of rainfall induced infiltration into separate sewerage. Water Science and Technology, 32(1), 161-168.

Bertrand-Krajewski, J.-L., Cardoso, M. A., Ellis, B., Frehmann, T., Giulianelli, M., Gujer, W., Pryl, K. (2006). Towards a better knowledge and management of infiltration and exfiltration in sewer systems: the APUSS project. Water Practice and Technology, 1(1).

Cahoon, L. B., Hanke, M. H. (2017). Rainfall effects on inflow and infiltration in wastewater treatment systems in a coastal plain region. Water Science and Technology, 75(8), 1909-1921.

De Ville, N., Le, H. M., Schmidt, L., Verbanck, M. A. (2017). Data-mining analysis of in-sewer infiltration patterns: seasonal characteristics of clear water seepage into Brussels main sewers. Urban Water Journal, 14(10), 1090-1096.

Heiderscheidt, E., Tesfamariam, A., Marttila, H., Postila, H., Zilio, S., Rossi, P. M. (2022). Stable water isotopes as a tool for assessing groundwater infiltration in sewage networks in cold climate conditions. Journal of Environmental Management, 302(B), 114107.

Kechavarzi, C., Keenan, P., Xu, X., Rui, Y. (2020). Monitoring the Hydraulic Performance of Sewers Using Fibre Optic Distributed Temperature Sensing. Water, 12(9), 2451.

Kracht, O., Gresch, M., Gujer, W. (2007). A Stable Isotope Approach for the Quantification of Sewer Infiltration. Environmental Science & Technology, 41(16), 5839-5845.

Kracht, O., Gresch, M., Gujer, W. (2008). Innovative tracer methods for sewer infiltration monitoring. Urban Water Journal, 5(3), 173-185.

Kracht, O., Gujer, W. (2005). Quantification of infiltration into sewers based on time series of pollutant loads. Water Science and Technology, 52(3), 209-218.

Lepot, M., Makris, K. F., Clemens, F. H. L. R. (2017). Detection and quantification of lateral, illicit connections and infiltration in sewers with Infra-Red camera: Conclusions after a wide experimental plan. Water Research, 122, 678-691.

Prigiobbe, V., Giulianelli, M. (2009). Quantification of sewer system infiltration using δ18O hydrograph separation. Water Science and Technology, 60(3), 727-735.

Schilperoort, R., Hoppe, H., de Haan, C., Langeveld, J. (2013). Searching for storm water inflows in foul sewers using fibre-optic distributed temperature sensing. Water Science and Technology, 68(8), 1723-1730.

Shelton, J. M., Kim, L., Fang, J., Ray, C., Yan, T. (2011). Assessing the Severity of Rainfall-Derived Infiltration and Inflow and Sewer Deterioration Based on the Flux Stability of Sewage Markers. Environmental Science & Technology, 45(20), 8683-8690.

Sherman, NB. J., Brink, P., TenBroek, M. J. (1998). Spatial and Seasonal Characterization of Infiltration/Inflow for a Regional Sewer System Model. Journal of Water Management Modeling, R200-13.

Wright, L.T., S. Dent, C., Mosley, P., Kadota., Y. Djebbar. (2001). Comparing Rainfall Dependent Inflow and Infiltration Simulation Methods. Journal of Water Management Modeling, R207-16.

Zhao, Z., Yin, H., Xu, Z., Peng, J., Yu, Z. (2020). Pin-pointing groundwater infiltration into urban sewers using chemical tracer in conjunction with physically based optimization model. Water Research, 115689.